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REPORT OF INVESTIGATIONS/1989

Heat-Resistant Steels Containing 8 pct Cr

By D. E. Larson

BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	mg	milligram
g	gram	mg/cm^2	milligram per square centimeter
h	hour		
in	inch	pct	percent
in/(in • min)	inch per inch minute	psi	pound (force) per square inch
lb	pound (mass)		
MPa	megapascal	wt pct	weight percent

HEAT-RESISTANT STEELS CONTAINING 8 pct Cr

By D. E. Larson[1]

ABSTRACT

The U.S. Bureau of Mines investigated Fe-base alloys containing 8 pct Cr with Ni, Al, and Si additions as substitutes for standard AISI Type 304 stainless steel (SS) in high-temperature oxidizing applications. The objective of this study was to reduce the amount of Cr required to make an austenitic stainless steel while retaining satisfactory workability, mechanical properties, and oxidation resistance.

Alloys prepared in this investigation had a composition of Fe-8Cr-1Mn-0.07C with varying amounts of Ni, Al, and Si. A minimum of 10 pct Ni was required to achieve an austenitic composition.

The microstructures of the austenitic alloys were very susceptible to room-temperature, deformation-induced martensitic transformations. When the alloys were cold worked or stressed, the materials had far greater tensile strengths than Type 304 SS at room temperature. At higher temperatures, tensile strengths and workability of several of the alloys were comparable to that of Type 304 SS.

Although martensitic transformation caused the room-temperature properties of the experimental alloys to be quite different than those of Type 304 SS, the superior oxidation resistance and similar hot workability of several alloys encourage their use as replacements for Type 304 SS.

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INTRODUCTION

Chromium is essential to the metallurgical industry in producing tool, stainless, and alloy steels. The stainless steel industry is the major consumer of Cr, accounting for 70 pct of the Nation's total usage in 1978 (*1*).[2]

Although most commonly used for their aqueous corrosion resistance, stainless steels are also used in critical heat-resistant applications requiring oxidation resistance and high-temperature strength. This investigation, as part of the U.S. Bureau of Mines effort to reduce our Nation's dependence upon foreign supplies of materials, was conducted to reduce the amount of Cr needed to make an austenitic stainless steel with heat-resistant properties equivalent to those of standard Type 304 SS. Standard Type 304 SS nominally contains 18 pct Cr and 8 pct Ni.

Several investigations were conducted on the subject of lower Cr stainless steels. Stephens (*2-3*) of the National Aeronautics and Space Administration (NASA) showed the potential of making lower Cr stainless steels with Si and Al additions by the development of a 12-pct-Cr alloy with oxidation resistance equal to that of Type 304 SS. Research at International Nickel Co. led to development of an Fe-12Cr-12Ni-(1-3)Al-(1-3)Si alloy for use in automobile exhaust systems and an Fe-10 Cr-24Ni-2Al-3Si alloy, both of which possess high-temperature strength and oxidation resistance (*4-5*).

Prior research at the Bureau started the development of Fe-(8-10)Cr-(10-14)Ni-1Mn-(0-4)Al-(0-8.5)Si alloys (*6*). Initial studies surveyed both the corrosion and oxidation properties of reduced-Cr alloys (*7*). Subsequent oxidation studies were performed to further define the mechanism of oxidation of an Fe-8Cr-14Ni-1Al-3.5Si-Mn alloy (*8*).

The purpose of the investigation described in this report was to reduce the Cr content of a stainless steel to 8 pct by using additions of Al and Si, both ferrite stabilizers, to provide oxidation resistance, and by using an addition of Ni to promote and retain an austenitic structure. These alloys were designed to have oxidation resistance, workability, and mechanical properties that would allow their direct substitution for Type 304 SS.

ALLOY PREPARATION

Alloys prepared in this investigation had a composition of Fe-8Cr-1Mn-0.07C with various Ni, Al, and Si additions. The base composition was selected to be at 8 pct Cr, with the Mn and C levels set below the Type 304 SS maximum content level of 2 pct Mn and 0.08 pct C. The Ni, Si, and Al contents were to be kept as low as possible while satisfactory properties were achieved. Electrolytic grades of Fe, Cr, Ni, and Mn materials and high-purity stocks of Al and Si were used in making these alloys. Carbon was introduced through an addition of pig iron.

Melts for the experimental alloys were made in two sizes (100-g buttons and 50-lb ingots). The first alloys were arc-melted on a copper hearth with a tungsten electrode in a closed vessel with a helium atmosphere and gave 100-g buttons, measuring approximately 2.4 by 1.3 by 0.4 in. The compositions of the 100-g melts are presented in the appendix. A set of 50-lb vacuum induction melts were later made of five representative alloys, designated A through E, selected for more intensive oxidation and mechanical property studies. The chemical analyses of these five alloys are presented in table 1. Following melting, all alloys were homogenized under vacuum at 1,200° C for 20 h to ensure a uniform microstructure throughout the alloy.

Table 1.–Chemical analyses of the five representative alloys, weight percent

Alloy	Fe	Cr	Ni	Mn	Al	Si	C
A	72.9	8.0	14.0	0.8	0.9	3.3	0.07
B	75.2	7.0	13.2	.3	1.0	3.2	.07
C	72.1	7.9	13.7	1.1	1.7	3.4	.07
D	71.5	8.3	14.2	.8	.9	4.2	.07
E	74.8	8.0	11.6	.3	.8	4.4	.06

DETERMINATION OF AUSTENITIC COMPOSITIONS

In order to be acceptable as replacements for standard Type 304 SS, the substitute alloys were required to have an austenitic structure for workability and high-temperature stress rupture resistance. Therefore, one of the basic goals of this study was to define the Ni, Al, and Si content requirements within the Fe-8Cr-1Mn-0.07C system to retain an austenitic microstructure at room temperature.

The structure of several selected alloys was defined through metallographic observations. A typical austenitic microstructure is shown in figure 1. The average American Society for Testing and Materials (ASTM) grain size of the austenitic materials was 6. Metallography was not performed on all materials, but following melting and homogenization, the percentage of austenite in each alloy was determined with a Magne-Gage[3] instrument.

[2]Italic numbers in parentheses refer to items in the list of references preceding the appendix at the end of this report.

[3]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

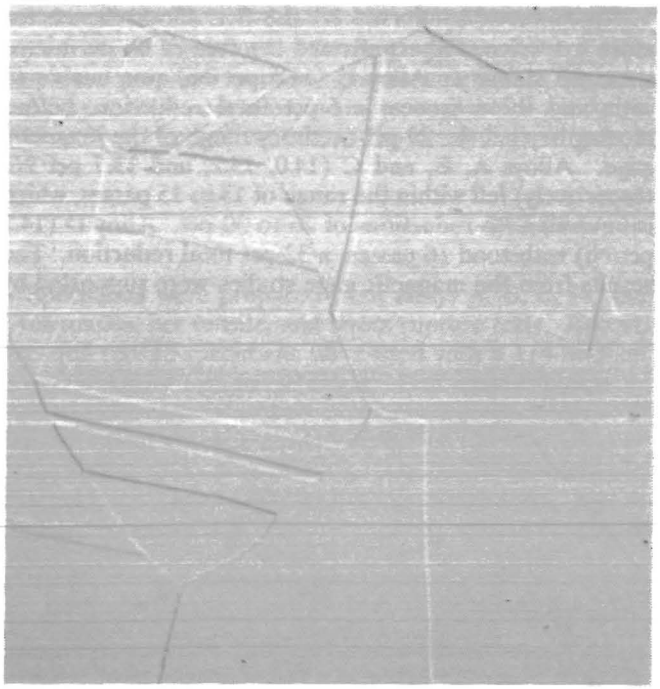

Figure 1.–Typical microstructure of austenitic alloys (X 400).

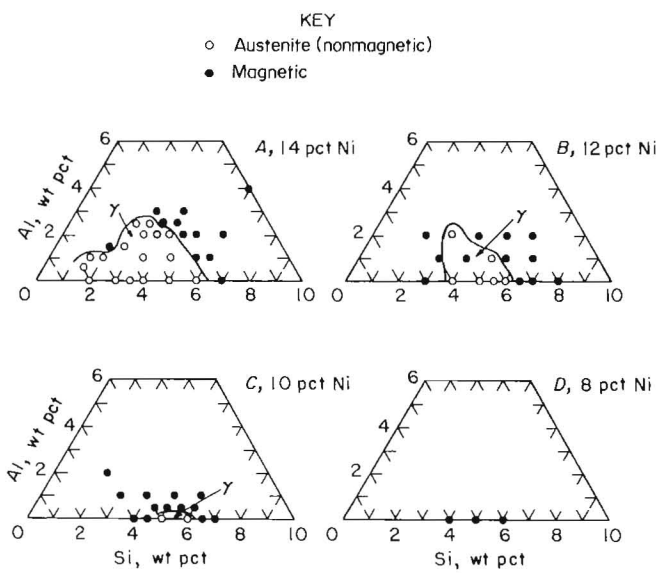

Figure 2.–Alloy phases as determined by magnetic gage.

The magnetic gage measures the strength of the attraction between a standard reference magnet and the alloy. The readings are expressed in terms of ferrite number, which is approximately equal to the percentage of magnetic structure present. From the magnetic gage readings, the amount of magnetic structure, which is mostly martensite in these alloys, versus the amount of nonmagnetic austenite could be determined. The range of the magnetic gage was from 0 to 29 pct magnetic structure within an otherwise austenitic matrix. An exact reading above 29 pct was not possible. The magnetic gage measurements of the alloys are presented in the appendix. For these alloys, analyses were either 8 pct magnetic or less, or they were greater than 29 pct magnetic. Alloys with readings of 8 pct or less magnetic were considered to be austenitic for this investigation. Type 304 SS had a value of 1 pct magnetic. The magnetic gage was used in accordance with the American Welding Society standard procedure (*9*).

It was known early in this investigation that the austenitic structure of the experimental alloys was largely controlled by the Ni content. Tests were then designed to set the limits on the Si and Al additions within the 14-, 12-, 10-, and 8-pct-Ni content levels so that an austenitic microstructure could be retained.

Austenitic alloy compositions were defined at the 14-, 12-, and 10-pct-Ni levels with varying Si or Al plus Si contents; there were no austenitic compositions that contained Al without Si nor were there any at the 8-pct-Ni level. Results of this study are summarized in figure 2. The area of the austenitic gamma phase region decreased in size as the Ni content of the alloy decreased.

The maximum amount of Al that can be present in an alloy and still have the alloy remain austenitic decreased as follows:

1. Two and one-half percent aluminum at the 14-pct-Ni, 3- to 3.5-pct-Si level;

2. Two percent aluminum at the 12-pct-Ni, 3-pct-Si level;

3. None at the 10-pct-Ni level.

The range of Si contents in alloys that retained an austenitic structure was from 1.5 to 6 pct Si at the 14-pct-Ni level, 4 to 6 pct Si at the 12-pct-Ni level, and only 5 to 6 pct Si at the 10-pct-Ni level. The compositions of alloys A through E were selected by their centralized location within the defined austenitic regions.

WORKABILITY

HOT WORKABILITY

A cursory examination was made of the hot workability of the experimental alloys. All 100-g buttons prepared in this study were hot rolled at 1,100° C from their initial thicknesses of approximately 0.4 in down to 0.100 in using 20-pct-reduction-in-thickness increments for an average of nine passes through the rolls. Materials were reheated between each pass to maintain rolling temperature.

The workability of an alloy was characterized using a comparative rating system developed at the Bureau's Albany Research Center for judging the imperfections and flaws of a 100-g button after hot rolling. To summarize this system, the number and size of rolling-induced imperfections of the alloy button were compared with 10 standards that have defined limits on the size and number of flaws. Through the use of these appraisal standards, an alloy was given a rating of 1 to 10. A rating of 10 represented the best hot workability (equal to Type 304 SS), and a rating of 1 represented the poorest hot workability.

The ratings of each of the alloys are in the appendix. These ratings varied across the entire scale range, with no definite correlations found between the rating and the alloy composition nor between the rating of the alloy and its microstructure. Twenty-one of the seventy-eight alloys had hot workability equivalent to that of Type 304 SS. Eight alloys, with ratings of 5 or lower, had serious workability problems that would limit their usage. Five additional alloys were not rated because they were very brittle and shattered before reaching the 0.100-in thickness.

COLD WORKABILITY

Initial cold-working studies indicated that the alloys in this series have an austenitic structure that is susceptible to a deformation-induced phase transformation to martensite. An example of a partial phase transformation to martensite is shown in figure 3. This transition-susceptible microstructure, called metastable austenite, is more closely associated with AISI Type 301 SS than with Type 304 SS.

For further analysis of the microstructure transition, test blanks were prepared from hot-rolled samples of selected austenitic compositions for evaluation of the cold workability. These blanks, approximately 1.0 by 1.0 by 0.100 in, were measured with the magnetic gage at nine points. The blanks were then cold rolled several times using a 0.002-in reduction in thickness per pass and checked with the magnetic gage at each point after each pass through the rolls. Cold working was stopped once the blank had a magnetic gage reading of over 29 pct.

Results of the cold-working transformation study indicated that the Ni content of the alloy played the major role in determining the stability of the microstructure. The effects of the Al and Si additions were not detectable under the large influence of the Ni content. Results are summarized in figure 4. The shaded areas represent the range of ferrite number values measured at the specific total reduction percentages. Alloys with 10 pct Ni were immediately susceptible to the phase transformation of austenite to martensite, with only one pass through the rolling mill required to move them beyond the 29-pct-accuracy range of the magnetic gage. Alloys with 12 pct Ni were very susceptible to transformation, withstanding only one to three passes for a total reduction of 2 to 6 pct. Alloys with 14 pct Ni were less susceptible, withstanding 13 to 15 passes or from 26- to 30-pct total reduction.

Experiments conducted on the five alloys chosen for more extensive study confirmed the role of Ni on microstructure stability. Alloy E (11.6 pct Ni) was unable to withstand three passes, a 6-pct total reduction, before moving beyond the 29-pct-accuracy range of the magnetic gage. Alloys A, B, and C (14.0, 13.2, and 13.7 pct Ni, respectively) fell within the range of 13 to 15 passes, which is equivalent to reductions of 26 to 30 pct. Alloy D (14.2 pct Ni) withstood 16 passes, a 32-pct total reduction. The results from the magnetic gage studies were supported by

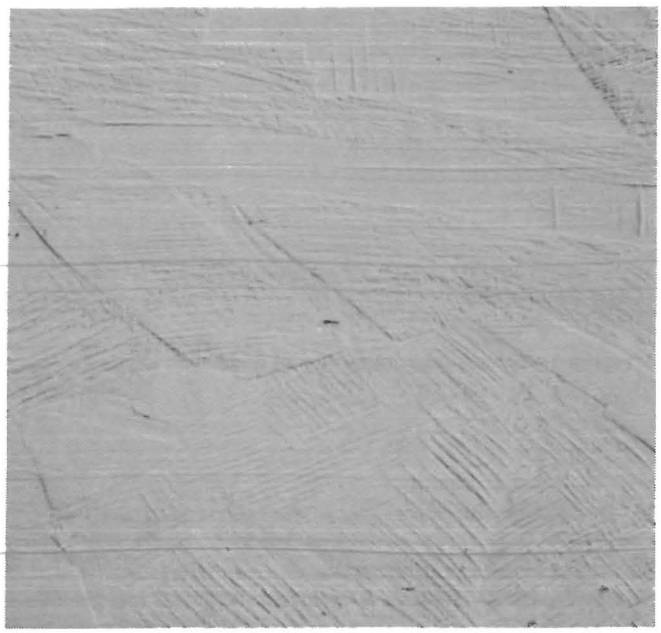

Figure 3.–Deformation-induced martensite in a cold-worked alloy (X 400).

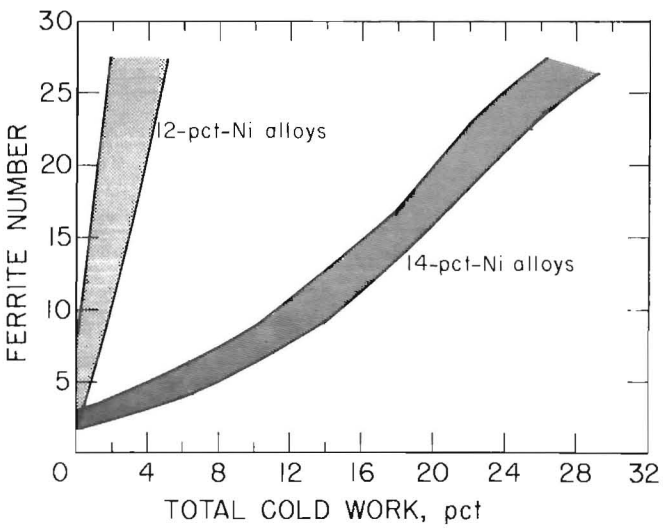

Figure 4.–Results of cold-workability transformation testing.

metallographic observations made on cold-worked specimens from all five alloys. Metallographic mounts of each alloy were prepared from test blanks with 6-, 12-, 18-, 24-, and 30-pct total reduction. An example of a specimen after a 30-pct reduction, where the martensitic structure becomes readily apparent within the austenitic grains, is shown in figure 3. The alloy shown in this figure had the same composition as the alloy in figure 1. This lack of microstructural stability later became apparent in the tensile testing performed on these alloys.

MECHANICAL TESTING

Specimens were prepared from alloys A, B, C, D, and E for tensile, hot tensile, and stress rupture tests. Round, threaded tensile specimens were used with a 1/4-in-diam cross section by 1-in gauge length. Hot tensile specimens were round, with a 1/4-in diam by 3-in gauge length. Stress rupture specimens were round and button headed, with a 1/4-in diam by 1-in gauge length. Specimens were also prepared from standard Type 304 SS for use in comparing results.

TENSILE TESTS

Tensile strength studies were conducted using a 0.05-in/(in • min) strain rate in a Baldwin Universal Testing Machine in accordance with the ASTM E8-79 standard (*10*). Duplicate tests were made on specimens of as-rolled material, and single determinations were made on specimens annealed at 1,065° C for 1 h.

Results of the room-temperature tensile tests are presented in table 2. All five of the alloys exhibited as-rolled tensile strengths higher than that for Type 304 SS. Alloys A through D had tensile strengths between 118,500 and 128,600 psi, which were from 40 to 50 pct higher than the tensile strength of Type 304 SS; this higher tensile strength was probably due to the transformation of the austenite to martensite. Alloy E had a tensile strength over 40 pct higher than those for the other four alloys and over double the strength of Type 304 SS; this higher strength was probably due to the lower Ni content of alloy E (12 pct versus 14 pct in alloys A through D), which in turn lowered the stability of the austenitic phase. Magnetic gage readings of the necked areas of the specimen showed the structure to be magnetic, which indicated martensite. Yield strengths of the five alloys ranged from below to above the value for Type 304 SS, with alloy A having the highest and alloy E exhibiting the lowest. Alloy D possessed the highest ductility of the five alloys, with an elongation value 50 pct higher and a reduction-in-area value 20 pct higher than the values for the standard Type 304 SS. The elongation values for alloys A, B, and C ranged from equal to 10 pct higher and the reduction-in-area values were 7 pct higher than those for Type 304 SS. Elongation was 40 pct lower for alloy E than for Type 304 SS, and reduction in area was almost equal.

The annealing of alloys A, C, and D caused considerable decreases in their tensile and yield strengths. The strength values for alloy B were only slightly decreased by the annealing, whereas annealing decreased the tensile strength and slightly increased the yield strength for alloy E. In comparison to annealed Type 304 SS, all of the annealed alloys had far greater tensile strengths and far lower yield strengths.

Table 2.–Results of tensile tests on alloys A, B, C, D, and E compared with Type 304 SS

Alloy	Tensile strength, psi	Yield strength, psi	Elongation, pct	Reduction in area, pct
As rolled:				
A	123,000	46,600	60	75
B	128,600	32,500	67	75
C	122,100	37,100	62	76
D	118,500	41,500	89	83
E	181,800	28,600	35	69
304 SS	85,000	38,000	60	70
Annealed:				
A	114,600	30,000	89	78
B	127,400	30,400	68	71
C	117,200	27,900	63	75
D	112,300	30,500	91	83
E	175,400	29,100	25	30
304 SS	85,000	35,000	60	70

HOT TENSILE TESTS

Hot tensile properties of the five alloys were evaluated in air at 700° C. The tests were performed in accordance with ASTM E151-64 (*11*). In this procedure, self-resistance heating of the specimens was used. Results are shown in table 3. Alloys A through D possessed higher ultimate tensile strengths than that of Type 304 SS, while the lower Ni alloy E had a lower strength than that of Type 304 SS. The yield strengths in comparison with Type 304 SS were 30 to 40 pct higher for alloys A, C, and D, about equal for alloy E, and 10 pct lower for alloy B. The percentage elongations and reductions in area were all lower than those for Type 304 SS, with the exception of alloy A, which had an equal reduction-in-area value.

Table 3.–Results of hot tensile tests at 700° C on alloys A, B, C, D, and E compared with Type 304 SS

Alloy	Tensile strength, psi	Yield strength, psi	Elongation, pct	Reduction in area, pct
A	39,700	28,600	30	50
B	38,900	18,200	25	32
C	43,500	27,900	18	23
D	39,200	26,100	31	44
E	36,400	20,400	18	23
304 SS . .	38,500	20,000	50	50

STRESS RUPTURE

Stress rupture studies were conducted on the five alloys at 700° C. The tests were performed in accordance with ASTM E139-79 (*12*), and the results are summarized in figure 5. Alloy A was the only one of the five alloys to have stress rupture values comparable with those for Type 304 SS. The other three alloys containing 14 pct Ni, alloys B, C, and D, had stress rupture values at varying degrees less than those of Type 304 SS. Alloy E, the 12-pct-Ni alloy, had the lowest stress rupture values. The ability of one of these alloys to substitute for Type 304 SS would depend on the demands of the application.

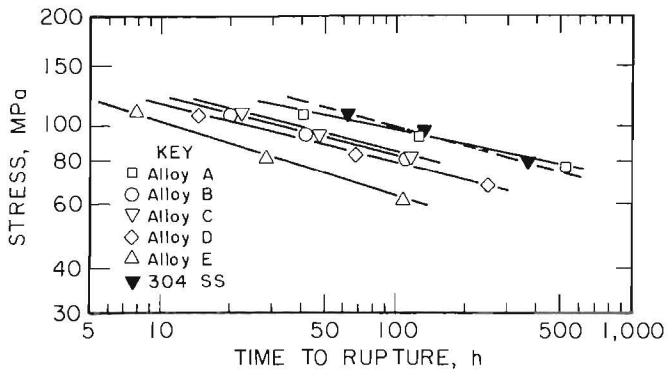

Figure 5.–700° C stress rupture data for 8-pct-Cr alloys.

OXIDATION TESTING

Oxidation studies were performed on selected alloys at 800° C in air at atmospheric pressure using a weight-gain technique in accordance with ASTM G54-77 (*13*). Test specimens consisted of approximately 1.25- by 1.0- by 0.100-in blanks polished to a 120-grit finish. Specimens were measured to determine their exact surface area, cleaned to remove all foreign matter, and weighed to the nearest 0.1 mg. Oxidation of the specimens was monitored during the test period by removing the specimens from the furnace for weighing at preselected exposure times.

200-h STATIC TEST

Specimens for oxidation-resistance screening studies were prepared from 18 selected 100-g button melts. The compositions of the selected alloys were chosen to provide information on the influence of Al, Si, and Ni additions and alloy microstructure on oxidation resistance. A specimen of Type 304 SS was included as a comparison standard. Intermediate weighings were taken at 25, 50, 75, 100, and 150 h during the 200-h total exposure time.

Of the 18 alloys, 12 had oxidation resistance superior to the resistance of standard Type 304 SS. The compositions are ranked, in order of decreasing oxidation resistance, in table 4, along with their total weight gain per unit area after 200 h exposure. The number one ranked material was the most resistant to oxidation. The value for Type 304 SS is presented according to its resistance and is ranked 13.

The protective oxide scale spalled and fell from the specimen surface of six alloys and Type 304 SS. In these cases, the alloy was considered to have failed the test at the time the spalling was noted during the intermediate weighings.

The five most oxidation-resistant alloys contained both Al and Si. The only Al-plus-Si alloy that had poorer resistance than Type 304 SS was alloy 41, which failed after 50 h of exposure. Six of the alloys containing only Si had better oxidation resistance than that of Type 304 SS. The three alloys without Si additions had poorer performances than Type 304 SS.

600-h STATIC TEST

For these experiments, duplicate specimens were prepared from each of the alloys A through E, along with a pair of Type 304 SS specimens. Intermediate weighings at 25, 50, 75, 100, 150, 200, 300, and 400 h were made during the 600-h total exposure time.

Results of the 600-h static oxidation tests are summarized in figure 6. All five alloys had greater resistance to oxidation than standard Type 304 SS. The Type 304 SS specimens gained weight over three times as fast as any of the 8-pct-Cr alloys and started to spall before reaching 100-h. At 200 h, alloys A through E had weight gains of 0.12, 0.07, 0.08, 0.13, and 0.13 mg/cm^2, respectively. All five alloys had excellent oxidation resistance.

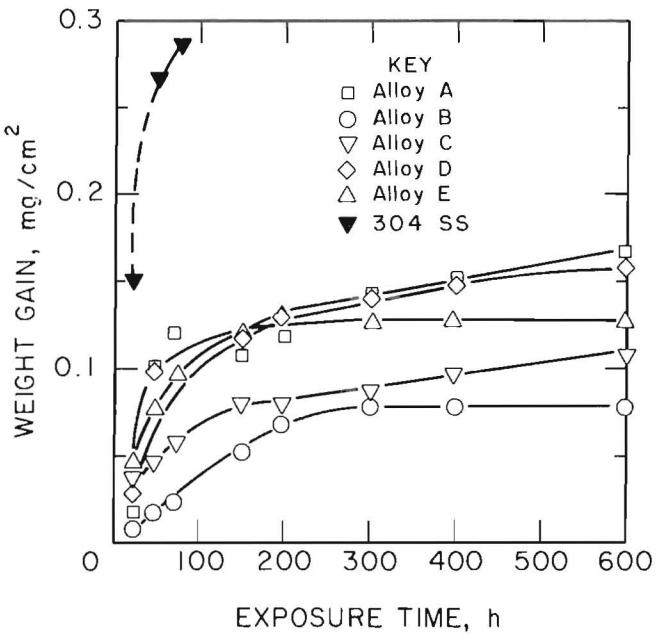

Figure 6.–600-h static oxidation results at 800° C.

Table 4.–Oxidation data on selected 8-pct-Cr alloys[1]

Ranking	Alloy	Additions, wt pct			Structure[2]		Weight gain per unit area, mg/cm²
		Ni	Al	Si	Initial	Final	
1	17	14	2	2	M	M	0.05
2	20	14	2	3.5	A	A	.06
3	43	12	1	4.5	A	M	.06
4	19	14	2	3	A	M	.07
5	29	14	3	3	M	M	.11
6	3	14	0	4	A	A	.14
7	60	10	0	5	A	M	.16
8	35	12	0	5	A	A	.17
9	34	12	0	4	A	A	.18
10	37	12	0	6	A	A	.22
11	21	14	2	4	A	A	.25
12	39	12	0	7	M	M	.49
13	304 SS	0	0	0	A	A	[3]
14	31	14	4	0	M	M	[3]
15	58	10	0	4	M	M	[4]
16	1	14	0	2	A	A	[4]
17	53	12	4	0	M	M	[4]
18	41	12	1	3	M	M	[4]
19	16	14	2	0	M	M	[5]

[1]Studies performed at 800° C in air at atmospheric pressure.
[2]Before and after oxidation treatment as determined by the magnetic gage; A = >90 pct austenite,
M = >28 pct martensite.
[3]Failed at 75 h.
[4]Failed at 50 h.
[5]Failed at 25 h.

SUMMARY AND CONCLUSIONS

The Bureau investigated Fe-base alloys containing 8 pct Cr with Ni, Al, and Si additions as substitutes for standard Type 304 SS in high-temperature oxidizing applications. As an austenitic structure was required, the limits of Ni, Al, and Si additions necessary to retain an austenitic microstructure at room temperature were defined. Nickel had the greatest effect on the structure of the alloys, with a minimum content of 10 pct Ni required to provide austenite. Increasing the Ni content above 10 pct also allowed increases in the content of Si and Al, both ferrite stabilizers, while retaining an overall austenitic structure.

A cursory examination of the hot workability of the alloys determined that many alloys have workability equal to that of Type 304 SS. No definite correlations were found between the hot workability of the alloys and their composition, nor between the workability and the alloy's microstructure.

Cold-workability studies indicated that the alloys in this series have an austenitic structure that is susceptible to a deformation-induced transition to martensite. The Ni content of the alloy played the major role in stabilizing the austenitic microstructure; increased Ni additions provided greater resistance to the transition to martensite. The effects of Al and Si additions were not detectable under the large influence of the Ni content.

Mechanical property experiments were performed on the five experimental alloys; alloys A, B, C, and D contained 14 pct Ni, and alloy E contained 12 pct Ni. The room-temperature tensile tests showed that the five alloys had far greater tensile strengths than Type 304 SS, probably because of the deformation-induced transformation of austenite to martensite. Yield strengths were greater for alloys A and D and were less for alloys B, C, and E than that for Type 304 SS. Results from the annealed specimens showed that considerable decreases occurred in tensile strengths. Yield strengths all fell below the value for Type 304 SS. Ductilities remained constant, with the exception of alloy E, which showed a large decrease in reduction in area, and alloy A, which increased its elongation value.

Alloys containing 14 pct Ni, alloys A, B, C, and D, had greater hot tensile strengths at 700° C than Type 304 SS, but alloy E, the 12-pct-Ni alloy, had less strength. Yield strengths for alloys A, C, and D were far greater than Type 304 SS; alloy E had a comparable strength; and alloy B had lower strength.

Stress rupture tests determined that only one of the compositions, alloy A, had slightly greater resistance than Type 304 SS, while the four remaining alloys, especially the 12-pct-Ni alloy (E), had less resistance.

Oxidation tests at 800° C identified 12 compositions with oxidation resistance superior to that of Type 304 SS. Static oxidation tests determined that the alloys with Al plus Si additions had better resistance than the alloys with Si additions alone.

Because of the deformation-induced transformation to martensite, the alloys developed in this study did not retain an austenitic microstructure when cold worked or stressed at room temperature. At elevated temperatures, where the transformation does not occur, the workability and some selected mechanical properties of specific compositions are comparable with Type 304 SS.

Although the deformation-induced transformation to martensite may limit their usage in certain applications, the superior oxidation resistance of several of the many compositions studied, along with their hot workability, would encourage their use as a substitute for Type 304 SS.

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APPENDIX.–ALLOY COMPOSITIONS FOR 100 g-BUTTONS

Alloy	Additions, wt pct[1] Ni	Al	Si	Magnetic structure[2] pct	Hot workability rating[3]
1	14	0	2	2	9
2	14	0	3	2	NA
3	14	0	4	3	8
4	14	0	5	1	6
5	14	0	6	2	10
6	14	0	7	>29	NA
7	14	.5	1.5	5	1
8	14	1	1.5	1	8
9	14	1	2	3	8
10	14	1	3.5	2	8
11	14	1	4.5	1	8
12	14	1	5.5	8	3
13	14	1	6	>29	4
14	14	1.5	2	>29	NA
15	14	1.5	2.5	4	10
16	14	2	0	>29	9
17	14	2	2	>29	10
18	14	2	2.5	4	8
19	14	2	3	2	10
20	14	2	3.5	1	10
21	14	2	4	1	7
22	14	2	4.5	8	9
23	14	2	5	>29	5
24	14	2	6	>29	NT
25	14	2.5	2.5	5	7
26	14	2.5	3	1	10
27	14	2.5	3.5	>29	8
28	14	2.5	4	>29	6
29	14	3	3	>29	2
30	14	3	4	>29	4
31	14	4	0	>29	9
32	14	4	6	>29	NT
33	12	0	3	>29	9
34	12	0	4	2	10
35	12	0	5	3	10
36	12	0	5.5	2	9
37	12	0	6	6	5
38	12	0	6.5	>29	9
39	12	0	7	>29	9
40	12	0	8	>29	NT
41	12	1	3	>29	9
42	12	1	4	5	9
43	12	1	4.5	3	10
44	12	1	5	1	8
45	12	1	5.5	>29	7
46	12	1	6.5	>29	9
47	12	2	0	>29	9
48	12	2	2	>29	10
49	12	2	3	3	10
50	12	2	4	>29	2
51	12	2	5	>29	9
52	12	2	6	>29	7
53	12	4	0	>29	9
54	12	4	3	>29	NT
55	12	4	6	>29	NT
56	12	6	0	>29	7
57	12	8	0	>29	9
58	10	0	4	>29	10
59	10	0	4.5	>29	NA
60	10	0	5	3	10
61	10	0	6	7	6
62	10	0	6.5	>29	7
63	10	0	7	>29	9
64	10	.5	4.5	>29	10
65	10	.5	5	>29	10
66	10	.5	5.5	>29	10
67	10	.5	6	>29	7
68	10	1	3	>29	10
69	10	1	4	>29	9
70	10	1	5	>29	8
71	10	1	6	>29	8
72	10	2	0	>29	10
73	10	2	2	>29	10
74	10	4	0	>29	9
75	10	6	0	>29	9
76	8	0	4	>29	10
77	8	0	5	>29	10
78	8	0	6	<29	6

NA Not Available. Alloy rating was influenced by handling during rolling.

NT Not tested. Alloy shattered before reaching final thickness.

[1]Base alloy Fe-8Cr-1Mn-0.07C.

[2]As determined by the magnetic gage.

[3]1 = poorest: 10 = best.

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